REMARKS

Prior to this Reply, Claims 38-137 were pending. Through this Reply, Claim 128 has been amended. No claims have been added or cancelled. Accordingly, Claims 38-137 are now at issue in the present case.

I.   Allowable Subject Matter

Applicants note, with appreciation, the Examiner's indication of the allowability of Claims 78-127. Such claims have not been amended and, accordingly, are still believed to be allowable.

The Examiner objected to Claims 42-44, 48, 51-54, 62-64, 72-74 and 131-134 as being dependent upon a rejected base claim. However, the Examiner indicated that such claims would be allowable if they were rewritten in independent form to include the limitations of their respective base claims and any intervening claims.

II.   Amendments to Drawings

The Examiner has objected to the drawings under 37 C.F.R. 1.83(a) since the circumferentially spaced spirals are not shown. The Examiner requires that the circumferentially spaced spirals be shown or be canceled from the claims.

In response, Applicants have amended the drawings to show the circumferentially spaced spirals.

The substitute specification describes the circumferentially spaced spirals as follows:

> In one example, the reference pattern includes a set of
> circumferentially spaced spirals. The spirals start at the OD of the
> disk 108 and end at the ID of the disk 108. The spirals have
> information written along their length that provide radial positions

for track following during SSW the servo bursts 130c on the tracks 132. (Page 15, lines 1-4).

In one case, each servo burst 130c is written a short time after the transducer 124 passes over a spiral. (Page 15, lines 11-12).

It is also possible to measure the PES on the spirals on both sides of the servo burst 130c and to interpolate a more accurate misposition of the servo burst 130c. That is, the ERC value can be calculated using an interpolated PES based on PES's measured from spirals on both sides of the servo burst 130c. (Page 16, lines 11-15).

Thus, the circumferentially spaced spirals extend from the outer diameter to the inner diameter of the disk 108 and occur before and after each servo burst 130c.

Applicants are submitting replacement Figures 1-5, 6A-1, 6A-2, 6B-1 and 6B-2 (contained on Replacement Sheets 1-8) to overcome this objection.

Figures 1-3 have not been amended, but are being submitted so that a complete set of drawings are provided.

Figure 4 has been added to show the circumferentially spaced spirals 146.

Figures 4, 5A-1, 5A-2, 5B-1 and 5B-2 have been renumbered as Figures 5, 6A-1, 6A-2, 6B-1 and 6B-2, respectively.

No new matter has been added. Figures 1-5, 6A-1, 6A-2, 6B-1 and 6B-2 constitute all of the drawings of the application.

III.   Claim Rejections – Szita et al.

The Examiner rejected Claims 38, 39, 41, 45-49, 55-59, 61, 65-69, 71, 75-77, 128, 129 and 135-137 under 35 U.S.C. § 102(e) as being anticipated by U.S. Patent No. 6,751,046 to Szita et al. (hereinafter "Szita et al.").

Szita et al. provides rulers on a disk, then determines correction factors for the rulers, then stores the correction factors in a table, then writes final servo patterns on the disk, and then reads the final servo patterns to adapt the correction factors.

The correction factors for the rulers are determined as the head sweeps from the inner diameter to the outer diameter of the disk. Each ruler is detected using a spindle motor index signal that occurs once per disk revolution, and a correction factor is determined for each ruler. Furthermore, the correction factor is synchronously averaged by reading the ruler over multiple revolutions of the disk to minimize non-repeatable disturbances.

Claim 38 recites "generating a PES using the transducer to read the reference pattern during a revolution of the disk" then "self-writing a servo burst on the disk using the transducer during the revolution of the disk, wherein the PES indicates RRO for the servo burst" and "calculating an ERC value for the servo burst using the PES." Thus, the transducer (1) reads the reference pattern to generate the PES and then (2) writes the servo burst during the same revolution of the disk.

Szita et al. fails to teach or suggest reading a ruler to determine a correction factor and then writing a final servo burst during the same revolution of the disk. Instead, Szita et al. reads a ruler to determine its correction factor during multiple revolutions of the disk, then reads the next ruler to determine its correction factor during multiple revolutions of the disk, and so on as the head sweeps from the inner diameter to the outer diameter of the disk. Thereafter, once the correction factors for all the rulers have been obtained, the final servo patterns are written.

Claim 48 is patentably distinguishable from Szita et al. for at least the same reasons as Claim 38.

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Claim 58 recites "self-writing . . . an A, B servo burst pair" and "generating a PES using the transducer to read the reference pattern after self-writing the A servo burst and before self-writing the B servo burst, wherein the PES indicates RRO for the B servo burst" and "calculating an ERC value for the B servo burst using the PES." Thus, the transducer reads the reference pattern to generate the PES (1) after writing the A servo burst and (2) before writing the B servo burst.

Szita et al. fails to teach or suggest reading a ruler to determine a correction factor after writing the A servo burst and before writing the B servo burst of an A, B servo burst pair. Instead, Szita et al. reads the rulers, determines the correction factors and then writes the final servo patterns.

Claim 68 is patentably distinguishable from Szita et al. for at least the same reasons as Claim 58.

Claim 128 recites "a controller that (1) generates a position error signal (PES) using the transducer to read the reference pattern while the transducer is at a radial position, (2) self-writes a servo burst on the disk using the transducer while using the PES to position the transducer at the radial position, wherein the PES indicates RRO for the servo burst and the transducer remains positioned at the radial position between reading the reference pattern and self-writing the servo burst, (3) calculates an ERC value for the servo burst using the PES." Thus, the transducer remains at the radial position during and between (1) generating the PES and (2) writing the servo burst.

Szita et al. fails to teach or suggest keeping the head positioned at a radial position during and between reading a ruler to determine a correction factor and writing a final servo pattern.

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Instead, Szita et al. sweeps the head from the inner diameter to the outer diameter of the disk to read the rulers and then writes the final servo patterns.

The Examiner asserts that "Szita et al disclose . . . providing a reference pattern (i.e., ruler) on the disk, generating a PES (i.e., position information) using the transducer to read the reference pattern during a revolution of the disk (column 6, lines 8-12), self-writing servo burst on the disk using the transducer during the revolution of the disk, wherein the PES indicates RRO for the servo burst (column 5, lines 30-33), calculating an ERC value (i.e., adapting correction factor) for the servo burst using the PES, and storing the ERC value on the disk (column 5, lines 53-57)."

Szita et al. says nothing about reading the ruler and writing the final servo pattern during the <u>same revolution</u> of the disk. Instead, Szita et al. reads the rulers to determine the correction factors during multiple revolutions of the disk and then writes the final servo patterns:

> The method provides for self servo writing by first calibrating a ruler on a disk surface. Correction factors to correct for eccentricity are determined. The final servo patterns are <u>then</u> written and the correction factors are modified to account for any variation in the [repeatable] disturbances and for errors caused by any non-repeatable disturbances. (Col. 2, lines 45-51) (Emphasis added.)

> Referring to FIG. 6, a flowchart illustrating a method for self servo writing according to the present invention is shown. The process begins at block 600 and thereafter passes to block 602, where a ruler is calibrated. The method continues at block 604 with activation of the servo system and application of the correction factors determined in the previous step. The final servo patterns are <u>then</u> written and the correction factors are modified for any variations in the repeatable disturbances (block 606). (Col. 5, lines 6-14) (Emphasis added).

> Typically, one correction factor should be determined for each ruler. Thus, the number of correction factors equals the number of rulers on the disk. In this exemplary embodiment, the rulers are numbered from 0 to n. Ruler 0 is typically defined as the

first ruler detected after a <u>once per revolution</u> index signal is obtained from the spindle motor. (Col. 6, lines 14-19) (Emphasis added).

In this exemplary embodiment, the correction table is synchronously averaged by reading the position information for <u>several revolutions</u> of the recording disk. Rotating the disk for <u>several revolutions</u> allows the noise generated by non-repeatable disturbances to be averaged over time and can therefore minimize the effects of the noise from non-repeatable disturbances. (Col. 6, lines 20-26) (Emphasis added).

The Examiner asserts that Szita et al. discloses generating a PES using the transducer to read the reference pattern during a revolution of the disk at column 6, lines 8-12, and then self-writing a servo burst on the disk using the transducer during the revolution of the disk at column 5, lines 30-33. However, the cited passages say nothing of the kind:

Next, the A burst is written and the correction factors are adapted to account for repeatable disturbances that vary at various points on the disk surface (block 706). (Col. 5, lines 30-33).

The position information is then determined by reading the magnitude of the signal generated by the ABCD bursts at each ruler (block 804). Next, the correction factor w_k is determined (block 806). The correction factor is then saved, as shown in block 808. (Col. 6, lines 8-12).

Fig. 6 illustrates self-servo writing by calibrating the ruler to generate the correction factors (block 602), then activating the servo system (block 604), and then writing the final servo patterns and modifying the correction factors (blocks 606 and 608). Fig. 7 illustrates blocks 606 and 608 in more detail. Fig. 8 illustrates block 602 in more detail.

The ruler is read (block 804) to determine the correction factor (block 806) and <u>then</u> the A burst of the final servo pattern is written and the correction factor is modified (block 706). This fails to teach or suggest that the ruler is read (block 804) and the final servo pattern is

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written (block 706) during the <u>same revolution</u> of the disk. If the Examiner disagrees, the

Examiner is requested to point to such teaching in Szita et al.

IV.   <u>Claim Rejections – Szita et al. and Codilian et al.</u>

The Examiner rejected Claims 40, 50, 60, 70, 88-91, 95-97 and 130 under 35 U.S.C. §

103(a) as being unpatentable over Szita et al. in view of U.S. Patent No. 6,091,564 to Codilian et

al. (hereinafter "Codilian et al.").

Codilian et al. discloses writing servo busts A/B in servo sectors 511, <u>then</u> writing

calibration bursts A*/B* in data sectors 512 along spiral path 612, <u>then</u> reading calibration bursts

A*/B* to measure and compensate for the non-linear PES response of MR head 100 to more

accurately micro-jog MR head 100, and <u>then</u> recording user data over calibration bursts A*/B*.

Codilian et al. says nothing about writing servo bursts A/B using calibration bursts A*/B* as a

reference. Instead, Codilian et al. says the opposite:

> The inventors presently contemplate recording the
> calibration bursts A* and B* <u>after</u> completely recording all of the
> normal servo sectors 511 in small, accurate radial increments. (Col.
> 10, lines 19-22) (Emphasis added).

Claim 40 recites "the reference pattern is circumferentially spaced spirals."

Szita et al. fails to teach or suggest that the rulers are circumferentially spaced spirals,

and Codilian et al. fails to cure this deficiency. Szita et al. in view of Codilian et al. might

suggest writing the calibration bursts <u>after</u> writing the final servo patterns but fails to suggest

forming the rulers as circumferentially spaced spirals <u>before</u> writing the final servo patterns.

Furthermore, the rulers correct for written-in eccentricity on the disk, whereas the calibration

bursts correct for non-linear PES response of the head. Therefore, the rulers and the calibration

bursts have different purposes, different formats and different operations, and there's no apparent reason why one would be modified in view of the other.

The Examiner asserts that "Codilian et al however, disclose a method of self-servo writing in a disk drive wherein a reference pattern is a spiral on the disk surface which is used for the purpose of writing servo bursts with reduced write time (see Fig. 13 and disclosure thereof and abstract)." However, Fig. 13 and the cited passages say nothing of the kind. If the Examiner disagrees, the Examiner is requested to point to such teaching in Codilian.

Claims 50, 60, 70, 88-91, 95-97 and 130 are patentably distinguishable from Szita et al. in view of Codilian et al. for at least the same reasons as Claim 40.

V.   Amendments to Specification

A substitute specification without claims (and a marked-up version thereof) is provided herein under 37 C.F.R. 1.125 to provide consistency with the amended drawings mentioned above. No new matter has been added.

The substitute specification provided herein replaces the previous substitute specification filed on July 27, 2005. Furthermore, since the previous substitute specification is the immediate prior version of the specification of record, the marked-up version of the substitute specification provided herein shows the changes relative to the previous substitute specification (see 37 C.F.R. 1.125(c)).

Applicants respectfully request that the substitute specification provided herein be entered and the previous substitute specification be withdrawn.

VI.   Additional Claim Fees

In determining whether additional claim fees are due, reference is made to the Fee

Calculation Table (below).

Fee Calculation Table

	Claims Remaining After Amendment		Highest Number Previously Paid For	Present Extra	Rate	Additional Fee
Total (37 CFR 1.16(c))	100	Minus	100	= 0	x $50 =	$0.00
Independent (37 CFR 1.16(b))	10	Minus	10	= 0	x $200=	$0.00

As set forth in the Fee Calculation Table (above), Applicants previously paid claim fees

for one-hundred (100) total claims and for ten (10) independent claims. Although Applicants

believe that no other fees are due, the Commissioner is hereby authorized to charge Deposit

Account No. 50-2198 for any fee deficiencies associated with filing this paper.

VII.   Conclusion

It is believed that the above comments establish patentability. Applicants do not

necessarily accede to the assertions and statements in the Office Action, whether or not expressly

addressed.

Applicants believe that the application appears to be in form for allowance. Accordingly,

reconsideration and allowance thereof is respectfully requested.

The Examiner is invited to contact the undersigned at the below-listed telephone number regarding any matters relating to the present application.

Respectfully submitted,

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Date: _March 28, 2006_

Marked-Up Version of

Substitute Specification Under 37 C.F.R. 1.125

Method and Apparatus for Runout Correction

During Self-Servo Writing

By

Thomas Melrose

and

James Hargarten

Related Application

This application claims priority from U.S. Provisional Patent Application Serial No.

60/403,583, filed on August 14, 2002, entitled "On the Fly SSW ERC," which is

incorporated herein by reference in its entirety.

Field of the Invention

The present invention relates to disk drives and, more particularly, to disk drive self-

servo writing and runout correction.

Background of the Invention

A disk drive is a data storage device that stores digital data in tracks on the surface of

a data storage disk. Data is read from or written to a track using a transducer that is held

close to the track while the disk spins about its center at a substantially constant angular

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velocity. To properly locate the transducer near the desired track during a read or write operation, a closed-loop servo control system reads a servo pattern from the disk surface to generate a position error signal (PES) and align the transducer with the desired track.

5   The servo pattern typically includes short servo bursts of a constant frequency signal. The servo bursts are written in a servo sector on the track, are very precisely located and are offset from either side of the track centerline. The servo bursts can be used to find the track centerline. Keeping the transducer on-center is required during both reading and writing to and from the track. The servo bursts allow the transducer to follow the track centerline

10   around the disk even when the track is perturbed (out-of-round) due to spindle wobble, disk slip and/or thermal expansion.

      Servo bursts are conventionally written on the disk in the disk drive by a dedicated, external servo track writer (STW). The STW typically uses a large granite block to support

15   the disk drive and reduce outside vibration. Unfortunately, the STW is expensive and requires a clean room since the disk and the transducer are exposed to allow access by the STW.

      Disk drives have been developed that use self-servo writing (SSW) for writing the

20   servo pattern. SSW typically uses a temporary pre-existing servo reference pattern on the disk to position the transducer while the servo bursts are written to the disk. SSW involves three largely distinct steps: (1) reading the reference pattern to provide precise timing, (2) positioning the transducer at a sequence of radial positions using amplitude variations in a

readback signal from the reference pattern as a sensitive position indicator, and (3) writing

the servo bursts at the times and radial positions defined by the first two steps to form

concentric circular tracks. SSW is described in U.S. Patent No. 5,907,447 to Yarmchuk et

al. SSW can also involve servo-propagation where the servo reader-to-writer offset allows

5   servoing on written servo bursts while writing other servo bursts.

In an ideal disk drive, the tracks are non-perturbed circles situated about the center of

the disk. These ideal tracks include a track centerline that is located at a known constant

radius from the disk center. In an actual system, however, it is difficult to write non-

10   perturbed circular tracks to the disk. Vibration, bearing defects, etc. can result in tracks that

are written differently from the ideal non-perturbed circular track shape. Positioning errors

created by the perturbed nature of these tracks are known as written-in repeatable runout

(WRRO).

15   The perturbed shape of these tracks complicates the transducer positioning during

read and write operations performed after SSW because the servo control system needs to

continuously reposition the transducer during track following to keep up with the constantly

changing radius of the track centerline with respect to the center of the spinning disk.

Furthermore, the perturbed shape of these tracks can result in track squeeze and track

20   misregistration errors during read and write operations.

Disk drives have been developed that measure the WRRO for each track, generate

compensation values (also known as embedded runout correction values or ERC values) and

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write the ERC values to servo sectors in the tracks. Thereafter, during read/write operations, the ERC values are used to position the transducer along an ideal track centerline. This is described in U.S. Patent No. 6,549,362 to Melrose et al. (the '362 patent), which is incorporated herein by reference.

5

Although the ERC values correct or reduce the WRRO, generating the ERC values can be time consuming. After SSW, the WRRO on each track is measured and then the ERC values are calculated. Finally, the ERC values are written to each servo sector of each track. This requires several revolutions of the disk to measure the WRRO on the track and

10 then more revolutions of the disk to write the ERC values to the track. In one example, this may require 12 or more revolutions of the disk to determine and write the ERC values for each track.

There is, therefore, a need for a disk drive that performs SSW and reduces the time

15 required to provide ERC values.

Brief Summary of the Invention

The present invention addresses the above need. The present invention provides a disk drive that determines WRRO during SSW. ERC values are calculated and then written

20 into corresponding servo sectors during SSW.

The disk drive can include a disk that includes a reference pattern which provides position information for self-writing servo bursts such that a PES is based on the reference pattern and the ERC values for the servo bursts are based on the PES.

5   The disk drive can also include a controller which implements the SSW of the present invention.

A method includes determining a first PES that indicates WRRO for first servo bursts using a transducer to read the reference pattern, self-writing the first servo bursts

10   using the transducer, calculating an ERC value for the first servo bursts based on the first PES, storing the ERC value in a corresponding servo sector, and then self-writing other servo bursts.

The method can include determining a second PES that indicates WRRO for second

15   servo bursts using the transducer to read the reference pattern, self-writing the second servo bursts using the transducer wherein the first and second servo bursts define a track centerline, and calculating the ERC value for the first and second servo bursts based on the first and second PES's.

20   In one embodiment, each servo sector includes a trimmed burst pattern, and self-writing the first servo bursts in each servo sector includes writing two first servo bursts such that one first servo burst trims the other first servo burst, thereby defining a first burst seam. In that case, the first PES indicates WRRO for the first burst seam. Further, self-writing the second servo bursts in each servo sector includes writing two second servo bursts such that

one second servo burst trims the other second servo burst, thereby defining a second burst

seam. In that case, the second PES indicates WRRO for the second burst seam. Each servo

sector can include a trimmed burst pattern comprising four radially offset, circumferentially

staggered servo bursts. Alternatively, each servo sector can include an untrimmed burst

5   pattern.

In another embodiment, determining the first PES and self-writing the first servo

bursts occurs during a first revolution of the disk, determining the second PES and self-

writing the second servo bursts occurs during a second revolution of the disk, and writing

10   the ERC value to the servo sector occurs during a third revolution of the disk.

Other objects, features, embodiments and advantages of the invention will be

apparent from the following specification taken in conjunction with the following drawings.

15   **<u>Brief Description of the Drawings</u>**

FIG. 1 is a diagrammatic representation of a top view of a hard disk drive with the

top cover removed;

FIG. 2 is a diagrammatic representation of a magnetic storage disk having a data

track that is compensated for runout in accordance with the present invention;

20   FIG. 3 is a diagrammatic representation of a servo burst pattern that may be used to

position a transducer with respect to a track centerline;

<u>FIG. 4 is a diagrammatic representation of the magnetic storage disk in FIG. 2</u>

<u>having a reference pattern that includes circumferentially spaced spirals;</u>

FIG. 54 is a flowchart of SSW according to the present invention;

FIGS. 65A-1 and 65A-2 together form a diagrammatic representation of a servo burst pattern written according to the SSW in FIG. 54; and

FIGS. 65B-1 and 65B-2 together form another diagrammatic representation of a

5 servo burst pattern written according to the SSW in FIG. 54.

Detailed Description of the Invention

While this invention is susceptible of embodiments in many different forms, there are shown in the drawings and will herein be described in detail, preferred embodiments of

10 the invention with the understanding that the present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the broad aspects of the invention to the embodiments illustrated.

Further, although in the description below, example embodiments of the present

15 invention are described in connection with a disk drive, it should be noted that the present invention is not intended to be limited to such systems.

FIG. 1 illustrates a typical computer disk drive. The disk drive 100 includes a base 104 and a magnetic disk (or disks) 108 (only one of which is shown in FIG. 1). The disk

20 108 is interconnected to the base 104 by a spindle motor (not shown) mounted within or beneath the hub 112 such that the disk 108 can be rotated relative to the base 104. Actuator arm assembly (or assemblies) 116 (only one of which is shown in FIG. 1) is interconnected to the base 104 by a bearing 120. The actuator arm assembly 116 includes a transducer (or

head) 124 (which includes both a read element and a write element) at an end to transfer data to and from a surface of the disk 108. A voice coil motor (VCM) 128 pivots the actuator arm assembly 116 about the bearing 120 to radially position the transducer 124 with respect to the disk 108. By changing the radial position of the transducer 124 with respect to

5 the disk 108, the transducer 124 can access different tracks 132 on the disk 108. The VCM 128 is operated by a controller 136 that is in turn operatively connected to a host computer (not shown). A channel 140 processes information read from the disk 108 by the transducer 124.

10 As illustrated in FIG. 2, the disk 108 is substantially circular in shape and includes a center point 200. The disk 108 also includes tracks 132 (only one of which is illustrated in FIG. 2) on an upper surface 204 of the disk 108 for storing digital data. The tracks 132 are divided into data fields 208a-208d and servo sectors (or hard sectors) 212a-212d. Generally, the data fields 208a-208d are used for storing user data as a series of magnetic transitions,

15 while the servo sectors 212a-212d are used for storing servo information, also as a series of magnetic transitions/bursts, that provide the transducer 124 with positioning information. In particular, the servo sectors 212a-212d provide the transducer 124 with information concerning its position over the disk 108. More particularly, the servo sectors 212a-212d provide information to the transducer 124 concerning the identity of the track 132 and the

20 servo sector 212 over which the transducer 124 is flying, and concerning the position of the transducer 124 with respect to the centerline of the track 132.

Although the disk 108 illustrated in FIG. 2 has a relatively small number of data tracks 132 and servo sectors 212, it can be appreciated that a typical disk drive contains a very large number of data tracks 132 and servo sectors 212. For example, disk drives having over 100,000 tracks per inch and 240 servo sectors per track are presently available.

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The disk drive 100 includes a servo control system 144 for controlling the position of the transducer 124 with respect to the track 132 being followed. In general, the servo control system 144 comprises the transducer 124 being positioned, which reads the position information from the servo sectors 212, the actuator arm assembly 116 that is carrying the transducer 124, the VCM 128, the controller 136 and the channel 140. As described in the '362 patent, the response of the servo control system 144 to a given input is given by the error transfer function of the servo control system 144.

10

The track 132 is ideally non-perturbed and ideally shares a common center 200 with the disk 108, such as the ideal track 216 illustrated in FIG. 2. Due to system imperfections, however, the actual written track 132 can be perturbed, such as the non-ideal track 132 illustrated in FIG. 2, as compared to the ideal track 216. A perturbed or non-ideal track 132 is difficult for the transducer 124 to follow because the position of the transducer 124 must constantly be adjusted by the servo control system 144. Perturbations from the ideal track center negatively impact track-to-track spacing. Consequently, track-to-track spacing must be increased to compensate for this position error, leading to lower disk capacity. Further, positioning of the transducer 124 is not as accurate on the perturbed track 132 as it would be on the ideal track 216.

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The perturbations in the track 132 due to positioning errors can be effectively reduced by SSW according to the present invention. The present invention provides a method and system that allows self-servo writing servo information (e.g., servo bursts) in

5 the tracks 132 along with correction information (e.g., ERC values) that compensate for position errors (e.g., WRRO). After SSW, during the disk drive 100 operation, the transducer 124 servoing on the track 132 can more closely follow the path of the ideal track 216 using the correction information.

10 The tracks 132 are each divided into interleaving data fields 208 and servo sectors 212. The servo sectors 212 are located in servo wedges that radially extend across the tracks 132. The servo sectors 212 include, among other things, information for use by the disk drive 100 in locating the transducer 124 above a desired track 132. When a host computer requests that data be read from or written to a particular data field 208 in a particular track

15 132, the transducer 124 must be moved to the track 132 and then must be positioned at a predetermined location relative to the centerline of the track 132 before the data transfer can take place. For purposes of illustrating the present invention, it will be assumed that the transducer 124 should be placed on the track centerline in order to read from and write to the disk 108. It should be understood that the invention is not limited to solely reading and

20 writing when the transducer 124 is placed at the track centerline. The track 132 is written to the disk 108 during SSW according to the present invention such that WRRO is effectively reduced.

FIG. 3 illustrates typical servo pattern 130b stored within a servo wedge 130a. The servo pattern 130b is used for centering the transducer 124 on a desired track 132. In FIG. 3, the tracks 132 are diagrammatically laid out linearly in a down-track (circumferential) direction from left to right, and in a cross-track (radial) direction from top to bottom. Three tracks 132 designated as tracks Tn-1, Tn and Tn+1 are shown. The servo pattern 130b includes radially offset, circumferentially staggered, final servo bursts 130c designated as A, B, C and D bursts. The servo bursts 130c define the centerlines 132a of the tracks 132. Thus, three centerlines 132a of three tracks 132 are defined by the servo bursts 130c. The servo bursts 130c provide analog information to the servo control system 144 for positioning the transducer 124. Other numbers of servo bursts and offset configurations are also possible. In this example, the A, B bursts form a burst pair and the C, D bursts form another burst pair. During normal operation of the disk drive 100, the A, B, C and D bursts are used by the servo control system 144 to position the transducer 124 at a track centerline.

SSW a track 132 that is later sampled by the servo control system 144 in positioning the transducer 124 to follow a track 132 which more closely resembles the ideal track 216 is now described. A temporary reference pattern of servo information (not shown) is initially provided on the disk 108 and used by the servo control system 144 to determine a PES for positioning the transducer 124 to write the servo bursts 130c. In a preferred implementation, an iterative process such as described in the '362 patent is applied to the reference pattern to reduce the RRO written into the reference pattern. The reference pattern with reduced RRO is then used for writing the servo bursts 130c.

The SSW described herein generates trimmed servo bursts. A trimmed servo burst has a circumferential edge (a top or bottom edge that extends in the circumferential direction) that is DC erased during a subsequent pass of the write element of the transducer 124 at a displaced radial position relative to the disk 108. The burst is trimmed to have e.g.

5 a bottom edge in radial alignment with a top edge of an adjacent burst. It is possible to trim a previously written burst during a single pass of the transducer 124 write element along a servo-writing path for writing another burst. However, the present invention is useful with untrimmed, and other trimmed, servo bursts. A discussion of trimmed and untrimmed bursts is provided in U.S. Patent No. 6,519,107 to Ehrlich et al., which is incorporated herein by

10 reference.

The SSW includes reading the reference pattern using the transducer 124 to generate a PES, calculating an ERC value based on the PES, self-writing the servo bursts 130c along a track 132 using the transducer 124, and writing the ERC value to the corresponding RRO

15 field 133 on the track 132 using the transducer 124. As such, the centerline of a mispositioned track 132 is effectively moved (repositioned) to a corrected track centerline location. After the SSW is completed, during operation of the disk drive 100, initially upon seeking to a track 132 and reading a first set of the servo bursts 130c, the servo control system 144 follows the original (uncorrected) track centerline until it reads the ERC value

20 from the corresponding RRO field 133, and thereafter moves the transducer 124 to the corrected track centerline location. Thereafter, the servo bursts 130c and the ERC values in the corresponding RRO fields 133 are used by the servo control system 144 to continue following the corrected (effectively re-positioned) track centerline.

In one example, in self-writing a track 132, the transducer 124 is positioned to write the A bursts along a circular path during a revolution of the disk 108. Then, in another revolution of the disk 108 the transducer is moved to write the C bursts. Then, in another

5   revolution of the disk 108 the transducer 124 is moved to write the B bursts, and the B bursts trim off the bottom edges of the A bursts, thereby defining first burst seams (transitions) 130d between the A bursts and the B bursts. In addition, the position errors in the burst seams 130d are measured by the transducer 124 reading the reference pattern and are stored in memory during the revolution of the disk 108. Then, in another revolution of the disk

10   108, the transducer 124 is moved to write the D bursts, and the D bursts trim off the bottom edges of the C bursts, thereby defining a second burst seam (transition) 130e between the C, D bursts. In addition, the position errors in the burst seams 130e are measured by the transducer 124 reading the reference pattern and are stored in memory during the revolution of the disk 108. Then, the position errors for the A, B bursts and the C, D bursts are used to

15   generate ERC values that are written by the transducer 124 to the RRO fields 133 corresponding to the A, B, C and D bursts of the track 132 during another revolution of the disk 108.

Other sequences for writing and trimming the servo bursts 130c are possible. The

20   motion of the transducer 124 defines where the burst seams 130d, 130e occur. Since the transducer 124 has motion due to non-repeatable runout (NRRO), the difference between the intended position of the burst seams 130d, 130e and the actual position of the burst seams 130d, 130e due to such movement of the transducer 124 is a capture of the NRRO and is

recorded in the servo bursts 130c by mispositioning the burst seams 130d, 130e as WRRO.
To compensate for the WRRO in the burst seams 130d, 130e, the ERC values are
determined and written to the RRO fields 133. For example, if the burst seam 130e is
located too far towards the outer diameter (OD) of the disk 108 (offset from ideal) by a
given amount, then the ERC values are calculated and written into the corresponding RRO
fields 133 during SSW, and after SSW, during operation of the disk drive 100, the servo
control system 144 uses the burst seams 130d, 130e and the ERC values in the
corresponding RRO fields 133 to position the transducer 124 towards the inner diameter
(ID) of the disk 108 by the given amount. As such, the servo control system 144 effectively
follows a track centerline at the intended (ideal/circular) track position.

Specifically, after the servo bursts 130c are written by SSW, in normal disk drive
100 operation, the servo control system 144 senses the position of the burst seams 130d
between the A, B bursts and the burst seams 130e between the C, D bursts for track
following. At each read/write position, one burst seam 130d and one burst seam 130e is
used. The servo control system 144 averages the observed position of the burst seams 130d,
130e and combines that average with the ERC value in the corresponding RRO field 133 to
generate the PES to control the VCM 128 for properly positioning the transducer 124 over
the track 132. Therefore, if during SSW, one or both of the burst seams 130d, 130e are
mispositioned slightly towards the ID or the OD of the disk 108, and thus slightly
mispositioned slightly away from the intended (ideal) position, then the ERC value in the
PES compensates for that mispositioning and the transducer 124 follows the path of an ideal

track 216 using the PES generated in each of the servo sectors 212 of the particular track

132.

The reference pattern is provided on the disk 108 before the SSW begins. An

5   iterative process such as described in the '362 patent is applied to the reference pattern to

reduce the RRO that is written into the reference pattern. The reference pattern with

reduced RRO is then used for writing the servo bursts 130c and calculating the ERC values.

In one example, as illustrated in FIG. 4, the reference pattern includes a set of

10   circumferentially spaced spirals 146 shown as spirals 146a-146d. The spirals 146 start at the

OD of the disk 108 and end at the ID of the disk 108. The spirals 146 have information

written along their length that provides radial positions for track following during SSW the

servo bursts 130c on the tracks 132. Although the disk 108 illustrated in FIG. 4 has a

relatively small number of spirals 146, it can be appreciated that the disk 108 contains a very

15   large number of spirals 146.

The WRRO in the burst seams 130d, 130e is related to the PES at the time the burst

seams 130d, 130e are written (created), and the PES is determined using the reference

pattern.

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In one case, each servo burst 130c is written a short time after the transducer 124

passes over a spiral 146. Because the NRRO is at a lower frequency than the spiral sample

rate, the transducer 124 cannot move too far off a track 132 after each spiral 146. As such,

the PES generated at the time the transducer 124 passes over and reads the last spiral 146

before the servo burst 130c is written is a good estimate of the position error when the servo

burst 130c is subsequently written. That is, the PES generated by reading the spiral 146

indicates the PES for the servo burst 130c. As a result, the PES for the servo burst 130c is

5   generated by reading the spiral 146 immediately before writing the servo burst 130c, and

without reading the servo burst 130c, thereby avoiding additional revolutions of the disk 108

that would otherwise be needed to read the servo burst 130c to generate the PES, and in turn

reducing the overall manufacturing time. It is preferable to record (store in memory) the

PES from the transducer 124 reading the spiral 146 at the time the transducer 124 crosses

10   the spiral 146, immediately before writing the servo burst 130c in a servo sector 212. In this

example, where four servo bursts are used, the PES's for the servo bursts 130c written in the

servo sectors 212 around a track 132 are used to back-calculate the ERC values to be written

in the RRO fields 133 on the track 132. In one version, the ERC values are written to the

corresponding RRO fields 133 around the track 132 in a revolution of the disk 108 after the

15   servo bursts 130c are written.

If the spiral 146 has been corrected for RRO, such as by the process described in the

'362 patent, then the PES from the spiral 146 is equal to the misposition of the transducer

124 from the ideal track centerline (the frequency content of the NRRO is significantly

20   lower than the servo sample rate). This PES from the spiral 146 is a good indication of the

misposition of the transducer 124 as the servo burst 130c is written. It is also possible to

measure the PES on the spirals 146 on both sides of the servo burst 130c and to interpolate a

more accurate misposition of the servo burst 130c. That is, the ERC value can be calculated

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using an interpolated PES based on PES's measured from spirals 146 on both sides of the

servo burst 130c. After the PES from the spiral 146 is generated such that the induced error

due to servo burst mispositioning is determined, the ERC value is calculated. Once the ERC

value has been calculated, the ERC value can be written to the RRO field 133. In this

5   example, where multiple servo bursts 130c are used, it will be necessary to reposition the

transducer 124 to the track centerline before writing the ERC values in the RRO fields 133

of the track 132.

An example SSW is now described. A process such as described in the '362 patent

10   is applied to the reference pattern (e.g., spiral tracks) that is used for servoing the transducer

124 as the transducer 124 writes the servo bursts 130c. This reduces, and can virtually

eliminate, the RRO written into the reference pattern. The reference pattern with reduced

RRO is then used for writing the servo bursts 130c and calculating the ERC values.

However, in writing the servo bursts 130c that define the burst seams 130d, 130e the NRRO

15   is recorded as WRRO in mispositioned burst seams 130d and/or 130e that perturb the track

132. The PES from the reference pattern immediately before writing the burst seams 130d,

130e indicates how far the burst seams 130d, 130e are mispositioned from their

ideal/intended position. The PES is obtained from the reference pattern immediately before

one servo burst 130c trims another servo burst 130c and is stored in memory.

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The PES from the reference pattern immediately before performing a burst write/trim

operation that controls a position of a burst seam 130d, 130e indicates how far the burst

seam 130d, 130e is mispositioned. That is, the mispositioning error (WRRO) is the stimulus

and the PES is the response. The mispositioning error can be calculated from the PES as described in the '362 patent.

The ERC values are calculated based on the PES from the reference pattern to

5   compensate for mispositioning the burst seams 130d, 130e. The ERC values are written to the RRO fields 133 during SSW, and after SSW is completed, during the disk drive 100 operation, the ERC values are read from the RRO fields 133 and combined with the corresponding servo bursts 130c position information to generate a PES for the VCM 128 to position the transducer 124 to compensate for mispositioning the burst seams 130d, 130e,

10   thereby reducing the overall track runout.

In general, the PES is derived by reading the reference pattern immediately before the burst seams 130d, 130e are written for a track 132. Obtaining the PES from a reference pattern is known by those skilled in the art, and need not be described herein. Preferably,

15   the position error data is obtained from the reference pattern, and the RRO written in the reference pattern is reduced by known methods.

FIG. 54 is a flowchart of SSW according to the present invention.

20   FIGS. 65A-1 and 65A-2 together show a diagrammatic representation of a servo burst pattern written according to the SSW in FIG. 54. Seven tracks 132 designated as tracks N, N+1, N+2, N+3, N+4, N+5 and N+6 are shown. The track centerlines are defined by the A, B, C and D bursts in each servo wedge. Track N+1 has SSW positioning error,

and the track centerline is at an incorrect location 150A rather than the correct location
150B. That is, the burst seams 130d, 130e in track N+1 cause the centerline of track N+1 to
be offset from its intended location. According to the present invention, the centerline for
track N+1 is effectively moved to the correct location 150B based on an ERC value in a
5   corresponding RRO field 133.

FIGS. 65B-1 and 65B-2 together show a diagrammatic representation of another
servo burst pattern written according to the SSW in FIG. 54. Four tracks 132 designated as
tracks N, N+1, N+2 and N+3 are shown. The track centerlines are defined by the A, B, C
10   and D bursts in each servo wedge. Further, the four tracks have corrected centerlines. The
inconsequential bursts serve to isolate adjacent tracks and prevent any correction
accumulation.

The A, B, C and D bursts correspond to four track modes. In particular, tracks N,
15   N+1, N+2, N+3, N+4, N+5 and N+6 have track modes 7, 5, 3, 1, 7, 5 and 3, respectively.
Each track mode indicates the sequence in which the bursts are written/trimmed, and the
corresponding PES from the bursts during normal operation of the disk drive 100 is based on
combinations of the burst difference values corresponding to the track mode. For example,
track mode 1 corresponds to the burst combination PES=-(A-B)+(C-D), track mode 3
20   corresponds to the burst combination PES=(A-B)+(C-D), track mode 5 corresponds to the
burst combination PES=(A-B)-(C-D), and track mode 7 corresponds to the burst
combination PES=-(A-B)-(C-D). Other track modes 0, 2, 4 and 6 are used for two burst
tracks (i.e., A, B bursts or C, D bursts).

In writing the servo bursts for track N using track mode 7, the A bursts are written in a revolution of the disk 108. Then, in another revolution of the disk 108 the C bursts for track N are written. Then, in another revolution of the disk 108 the B bursts are written and

5   each B burst trims the bottom edge of a corresponding A burst. The trimmed portion of the A burst, which includes the bottom edge of the A burst, is represented as a dashed box designated as "A trimmed." During the revolution of the disk 108 in which each A burst is trimmed, the PES that indicates the position of the A, B burst seam 130d is read from the reference pattern and stored in memory. Then, in another revolution of the disk 108 the D

10   bursts are written and each D burst trims a corresponding C burst. The trimmed portion of the C burst, which includes the bottom edge of the C burst, is represented as a dashed box designated as "C trimmed." During the revolution of the disk 108 in which each C burst is trimmed, the PES that indicates the position of the C, D burst seam 130e is read from the reference pattern and stored in memory. The recorded PES's are then used to determine

15   ERC values that are written into the RRO fields 133.

Referring back to FIG. 54, the SSW involves writing/trimming the servo bursts from bottom to top, in sequence, in FIGS. 65B-1 and 65B-2. Writing the four burst servo pattern is performed in eight steps which represent the four track modes. The process starts at a

20   track mode (e.g., track mode 1) and cycles through the track modes depending on the steps.

The steps in FIG. 54 are also shown FIGS. 65B-1 and 65B-2, from bottom to top, in sequence. Each step is aligned with the respective burst writing/trimming operation, with

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further explanation provided at the bottom of FIG. 65B-2. Referring to FIG. 54 in conjunction with the FIGS. 65B-1 and 65B-2, starting from track N+3 at the bottom of FIG. 65B-2 and moving from the bottom of FIG. 65B-2 to the top of FIG. 65B-2, from the top of FIG. 65B-2 to the bottom of FIG. 65B-1, and from the bottom of FIG. 65B-1 to the top of FIG. 65B-1, the sequential steps for writing the servo bursts for the four tracks N, N+1, N+2 and N+3 are as follows:

1) The B bursts are written in a disk 108 revolution (step 400);

2) The D bursts are written in another disk 108 revolution (step 402);

3) The A bursts are written in another disk 108 revolution and each A burst trims a corresponding B burst (inconsequential burst) (step 404);

4) The C bursts are written in another disk 108 revolution, each C burst trims a corresponding D burst (creating C, D burst seams 130e) and the PES (PESc) from the reference pattern for each C burst (and C, D burst seam) is recorded (e.g., stored in memory in the controller 136) (step 406);

5) The B bursts are written in another disk 108 revolution, each B burst trims a corresponding A burst (creating A, B burst seams 130d) and the PES (PESb) from the reference pattern for each B burst (and A, B burst seam) is recorded (step 408);

6) The just stored PES's (PESb and PESc) are used to determine an ERC value and the ERC value is written to the corresponding RRO field (step 410);

7) The D bursts are written in another disk 108 revolution and each D burst trims a corresponding C burst (inconsequential burst) (step 412);

8)   The A bursts are written in another disk 108 revolution, each A burst trims a corresponding B burst (creating A, B burst seams 130d) and the PES (PESa) from the reference pattern for each A burst (and A, B burst seam) is recorded (step 414);

9)   The C bursts are written in another disk 108 revolution, each C burst trims a corresponding D burst (creating C, D burst seams 130e) and the PES (PESc) from the reference pattern for each C burst (and C, D burst seam) is recorded (step 416);

10)   The just stored PES's (PESa and PESc) are used to determine an ERC value and the ERC value is written to the corresponding RRO field (step 418);

11)   The B bursts are written in another disk 108 revolution and each B burst trims a corresponding A burst (inconsequential burst) (step 420);

12)   The D bursts are written in another disk 108 revolution, each D burst trims a corresponding C burst (creating C, D burst seams 130e) and the PES (PESd) from the reference pattern for each D burst (and C, D burst seam) is recorded (step 422);

13)   The A bursts are written in another disk 108 revolution, each A burst trims a corresponding B burst (creating A, B burst seams 130d) and the PES (PESa) from the reference pattern for each A burst (and A, B burst seam) is recorded (step 424);

14)   The just stored PES's (PESa and PESd) are used to determine an ERC value and the ERC value is written to the corresponding RRO field (step 426);

15)   The C bursts are written in another disk 108 revolution and each C burst trims a corresponding D burst (inconsequential burst) (step 428);

16)   The B bursts are written in another disk 108 revolution, each B burst trims a corresponding A burst (creating A, B burst seams 130d) and the PES (PESb) from the reference pattern for each B burst (and A, B burst seam) is recorded (step 430);

17)   The D bursts are written in another disk 108 revolution, each D burst trims a corresponding C burst (creating C, D burst seams 130e) and the PES (PESd) from the reference pattern for each D burst (and C, D burst seam) is recorded (step 432);

18)   The just stored PES's (PESb and PESd) are used to determine an ERC value and the ERC value is written to the corresponding RRO field (step 434); and so on.

The calculation of the ERC values is dependent on the servo write technique being used. For example, if in the example of FIGS. 54, 65A-1, 65A-2, 65B-1 and 65B-2 a one-pass trimmed process writes the servo bursts, the ERC calculation is track mode dependent according to Table 1 below, where x is a positive integer:

Table 1

Track Mode	Track Number	Servo Track Number	PES	ERC
5	4x+0	3x+0	(A-B)-(C-D)	-(PESa+PESd)/2
3	4x+1	3x+1	(A-B)+(C-D)	-(PESa+PESc)/2
1	4x+2	3x+2	-(A-B)+(C-D)	-(PESb+PESc)/2
7	4x+3	3x+2	-(A-B)-(C-D)	-(PESb+PESd)/2

In another example, if a one-pass untrimmed process is used to write the servo bursts, the ERC calculation is ERC=-(PESa+PESb+PESc+PESd)/4, independent of the track mode. As those skilled in the art will recognize, similar calculations can be used for processes with multiple writes and independent trims.

As those skilled in the art will appreciate, the transducer 124 is moved under PES and timing control to write the various servo bursts 130c at different radial positions on the

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disk 108. Further, the transducer 124 is moved to write the RRO fields 133. In one

implementation, the transducer 124 is controlled to back-up one and a half servo steps to

write the RRO field 133 that corresponds to the track centerline. In another implementation,

if backing-up to write the RRO fields 133 interrupts the SSW then the RRO fields 133 are

5   written to a convenient track location as soon as the ERC values are calculated without

backing-up the transducer 124, and in a later step (e.g., a test process) the RRO fields 133

are "moved" by reading the ERC values therein and re-writing the ERC values at the desired

track location. In accordance with another aspect of the present invention, if the micro-jog

(reader-to-writer offset) profile for the transducer 124 is determined, then the RRO

10   correction for the read position can also be calculated.

The present invention is applicable to other servo burst patterns and other burst

numbers (e.g., a six burst system) by taking into account the servo burst relationships and

how the servo bursts trim one another. The present invention is also applicable to

15   independent trim passes (e.g., the burst trim passes are separate from the burst write passes).

The present invention is also applicable to servo writing that uses multiple writes, where e.g.

the A burst is written and trimmed twice and the average of the A, B bursts is used. The

mispositioning of each servo burst is the sum of the PES's due to recorded NRRO and

whatever correction is performed when correcting the spirals 146 for RRO. This indicates

20   the mispositioning of each servo burst which is used to calculate the ERC values. In one

example, the ERC values are stored in memory until they are written to the RRO fields 133.

Typically, the ERC values for one or more revolutions of the disk 108 are stored in memory

for the current track 132 until the ERC values are written to the RRO fields 133 during

SSW. Depending on how the ERC values are used (i.e., added to, or subtracted from, the PES) by the servo control system 144 during normal operation of the disk drive 100, the ERC values can have a negative or positive value. In this example, the ERC values are effectively subtracted from the PES.

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After SSW, during normal operation of the disk drive 100, the transducer 124 reads the servo bursts 130c in each servo sector 212 of a desired track 132. If the transducer 124 is placed at the burst seam 130d between the A, B bursts, the readback signal from the transducer 124 includes half the signal value of the A burst and half the signal value of the B burst. If the transducer 124 is shifted towards the A burst, the magnitude of the A burst increases and magnitude of the B burst decreases. The same applies to the C, D burst pair. The A, B and C, D bursts are shifted in position from each other by a fraction of the track width, such as 1/3 track width in this example. For positioning the transducer 124, the signal induced to the transducer 124 from the flux transitions in the servo bursts 130c is decoded by demodulating to form difference values (difference signals) including A-B and C-D phases. The transducer 124 position tracking information is decoded using combinations of the A-B burst phase and the C-D burst phase depending on the radial position of the transducer 124 relative to the track centerline. Further, the ERC value from the corresponding RRO field 133 is read by the transducer 124 and combined with the burst phase difference signals to obtain the PES for positioning the transducer 124. The '362 patent describes combining ERC values with burst phase values for servo control of the transducer during normal disk drive operation.

The PES indicates the distance between the center of the transducer 124 and the centerline of the desired track 132. For a requested read/write operation, the PES is used by the disk drive 100 to position the transducer 124 closer to the desired (centered) position. This centering process is repeated for each successive servo sector 212 on the track 132 until

5   the requested read/write operation is performed in the appropriate data field 208. It should be appreciated that other schemes for storing servo information on the disk, such as A, B bursts, zones, constant linear density (CLD) recording, split data fields, and/or hybrid servo can also be used.

10   The present invention can be applied to SSW where temporary servo information such as the reference pattern described above is used for timing and transducer positioning to write the final servo patterns. This may include printed media, partial write systems and self-propagation servo write systems, and can be applied using multi pass writes and trims, as those skilled in the art can appreciate. Because the temporary servo information will

15   inherently have RRO, it is necessary to remove the RRO with a real-time runout correction system to circularize the temporary servo information before using it to write the final servo pattern. The correction to cancel out the NRRO is added to whatever correction is needed to circularize the temporary servo information.

20   As known to those skilled in the art, in addition to the logic blocks shown in the drawings, the various methods and architectures described herein can be implemented as computer instructions for execution by a microprocessor, ASICs, firmware, logic circuits, etc.

The present invention has been described in considerable detail with reference to

certain preferred versions thereof; however, other versions are possible. Therefore, the spirit

and scope of the appended claims should not be limited to the description of the preferred

5   versions contained herein.

Abstract

A disk drive self-servo writes on a storage disk. Servo bursts are self-written along a track using a transducer, a position error signal (PES) indicating repeatable runout due (RRO) for the servo bursts is determined using a reference pattern, an embedded runout

5   correction (ERC) value is calculated based on the PES and stored in a corresponding servo sector, and then the disk drive self-writes other servo bursts.